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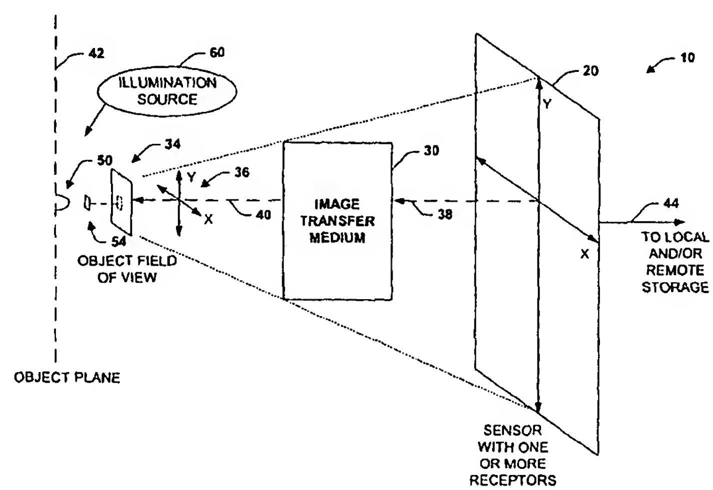
[Continued on next page]

(54) Title: IMAGING SYSTEM AND METHODOLOGY EMPLOYING RECIPROCAL SPACE OPTICAL DESIGN



(57) Abstract: An imaging system (10) and methodology (600) is provided to facilitate optical imaging performance. The system (10) includes a sensor (20) having one or more receptors and an image transfer medium (30) to scale the sensor and receptors to an object field of view (54). A computer (824), memory (864), and/or display (864) associated with the sensor (20) provides storage and/or display of information relating to output from the receptors to produce and/or process an image, wherein a plurality of illumination sources (60) can also be utilized in conjunction with the image transfer medium (30). The image transfer medium (30) can be configured as a k-space filter (110) that correlates a pitch (116) associated with the receptors to a diffraction-limited spot (50) within the object field of view (54), wherein the pitch (116) can be unit-mapped to about the size of the diffraction- limited spot (50) within the object field of view (54).

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(BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report*
— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Title: IMAGING SYSTEM AND METHODOLOGY EMPLOYING RECIPROCAL SPACE OPTICAL DESIGN

RELATED APPLICATION

This application claims the benefit of U.S. Patent Application Serial No. 09/900,218, which was filed July 6, 2001, and entitled IMAGING SYSTEM AND METHODOLOGY EMPLOYING RECIPROCAL SPACE OPTICAL DESIGN.

TECHNICAL FIELD

The present invention relates generally to image and optical systems, and more particularly to a system and method to facilitate imaging performance *via* an image transfer medium that projects characteristics of a sensor to an object field of view.

BACKGROUND OF THE INVENTION

Microscopes facilitate creating a large image of a tiny object. Greater magnification can be achieved if the light from an object is made to pass through two lenses compared to a simple microscope with one lens. A compound microscope has two or more converging lenses, placed in line with one another, so that both lenses refract the light in turn. The result is to produce an image that is magnified more than either lens could magnify alone. Light illuminating the object first passes through a short focal length lens or lens group, called the objective, and then travels on some distance before being passed through a longer focal length lens or lens group, called the eyepiece. A lens group is often simply referred to singularly as a lens. Usually these two lenses are held in paraxial relationship to one another, so that the axis of one lens is arranged to be in the same orientation as the axis of the second lens. It is the nature of the lenses, their properties, their relationship, and the relationship of the objective lens to the object that determines how a highly magnified image is produced in the eye of the observer.

The first lens or objective, is usually a small lens with a very small focal length. A specimen or object is placed in the path of a light source with sufficient intensity to

illuminate as desired. The objective lens is then lowered until the specimen is very close to, but not quite at the focal point of the lens. Light leaving the specimen and passing through the objective lens produces a real, inverted and magnified image behind the lens, in the microscope at a point generally referred to as the intermediate image plane. The second lens or eyepiece, has a longer focal length and is placed in the microscope so that the image produced by the objective lens falls closer to the eyepiece than one focal length (that is, inside the focal point of the lens). The image from the objective lens now becomes the object for the eyepiece lens. As this object is inside one focal length, the second lens refracts the light in such a way as to produce a second image that is virtual, inverted and magnified. This is the final image seen by the eye of the observer.

Alternatively, common infinity space or infinity corrected design microscopes employ objective lenses with infinite conjugate properties such that the light leaving the objective is not focused, but is a flux of parallel rays which do not converge until after passing through a tube lens where the projected image is then located at the focal point of the eyepiece for magnification and observation. Many microscopes, such as the compound microscope described above, are designed to provide images of certain quality to the human eye through an eyepiece. Connecting a Machine Vision Sensor, such as a Charge Coupled Device (CCD) sensor, to the microscope so that an image may be viewed on a monitor presents difficulties. This is because the image quality provided by the sensor and viewed by a human eye decreases, as compared to an image viewed by a human eye directly through an eyepiece. As a result, conventional optical systems for magnifying, observing, examining, and analyzing small items often require the careful attention of a technician monitoring the process through an eyepiece. It is for this reason, as well as others, that Machine-Vision or computer-based image displays from the aforementioned image sensor displayed on a monitor or other output display device are not of quality perceived by the human observer through the eyepiece.

SUMMARY OF THE INVENTION

The following presents a simplified summary of the invention in order to provide a basic understanding of some aspects of the invention. This summary is not an extensive overview of the invention. It is intended to neither identify key or critical elements of the

CLAIMS

What is claimed is:

1. An imaging system, comprising:

a sensor having one or more receptors; and

an image transfer medium to scale the one or more receptors to an object field of view.

2. The system of claim 1, the image transfer medium providing a k-space filter that correlates a pitch associated with the one or more receptors to a diffraction-limited spot within the object field of view.

3. The system of claim 2, the pitch being unit-mapped to about the size of the diffraction- limited spot within the object field of view.

4. The system of claim 1, the image transfer medium further comprising at least one of an aspherical lens, a multiple lens configuration, a fiber optic taper, an image conduit, and a holographic optic element.

5. The system of claim 1, the sensor further comprising an M by N array of pixels associated with the one or more receptors, M and N representing integer rows and columns respectively, the sensor further comprising at least one of a digital sensor, an analog sensor, a Charge Coupled Device (CCD) sensor, a CMOS sensor, a Charge Injection Device (CID) sensor, an array sensor, and a linear scan sensor.

6. The system of claim 1, further comprising a computer and a memory to receive an output from the sensor, the computer at least one of stores the output in the memory, performs automated analysis of the output in the memory, and maps the memory to a display to enable manual analysis of an image.

7. The system of claim 1, further comprising an illumination source to illuminate one or more non-luminous objects within the object field of view, the illumination source further comprises at least one of a Light Emitting Diode, wavelength-specific lighting, broad-band lighting, continuous lighting, strobed lighting, Kohler illumination, Abbe illumination, phase-contrast illumination, darkfield illumination, brightfield illumination, Epi illumination, coherent light, non-coherent light, visible light and non-visible light, the non-visible light being suitably matched to a sensor adapted for non-visible light.

8. The system of claim 7, the non-visible light further comprising at least one of infrared and ultraviolet wavelengths.

9. The system of claim 1, further comprising an associated application, the application including at least one of imaging, control, inspection, microscopy automated analysis, bio-medical analysis, cell colony counting, histology, frozen section analysis, cellular cytology, Haematology, pathology, oncology, fluorescence, interference, phase analysis, biological materials analysis, particle sizing applications, thin films analysis, air quality monitoring, airborne particulate measurement, optical defect analysis, metallurgy, semiconductor inspection and analysis, automated vision systems, 3-D imaging, cameras, copiers, FAX machines and medical systems applications.

10. A method of producing an image, comprising:

determining a pitch size between adjacent pixels on a sensor;

determining a resolvable object size in an object field of view; and

scaling the pitch size through an optical medium to correspond with the resolvable object size.

11. A machine vision system, comprising:

an imaging system for collecting image data from a product or process, comprising:

a sensor having one or more receptors; and

at least one optical device to direct light from an object field of view to the one or more receptors of the sensor, the at least one optical device provides a mapping of receptor size to about a size of a diffraction limited object appearing in the object field of view; and

a controller that receives the image data and employs the image data in connection with fabrication or control of the product or process.

12. The machine vision system of claim 11 being employed in a semiconductor-based fabrication system.

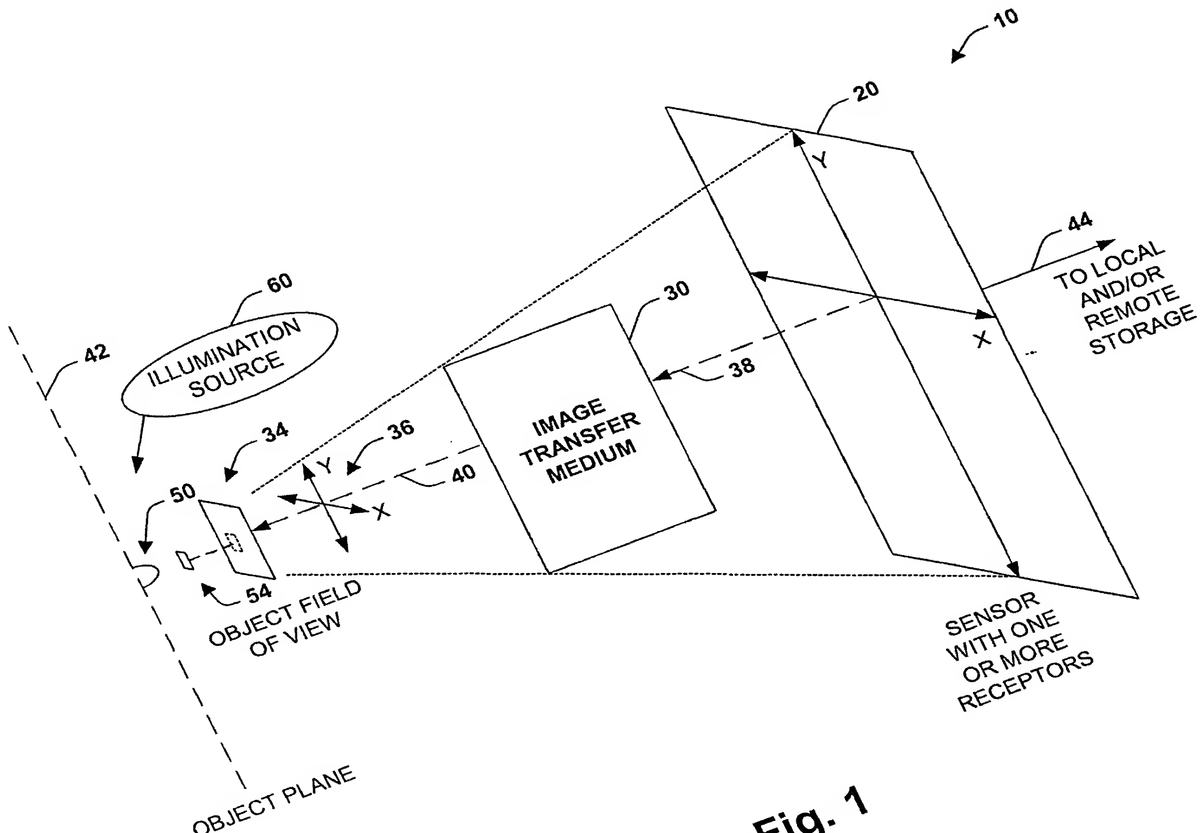
10
20
Y
X
44
TO LOCAL AND/OR REMOTE STORAGE
SENSOR WITH ONE OR MORE RECEPTORS
30
IMAGE TRANSFER MEDIUM
38
40
36
Y
X
34
60
ILLUMINATION SOURCE
42
50
54
OBJECT FIELD OF VIEW
OBJECT PLANE

Fig. 1

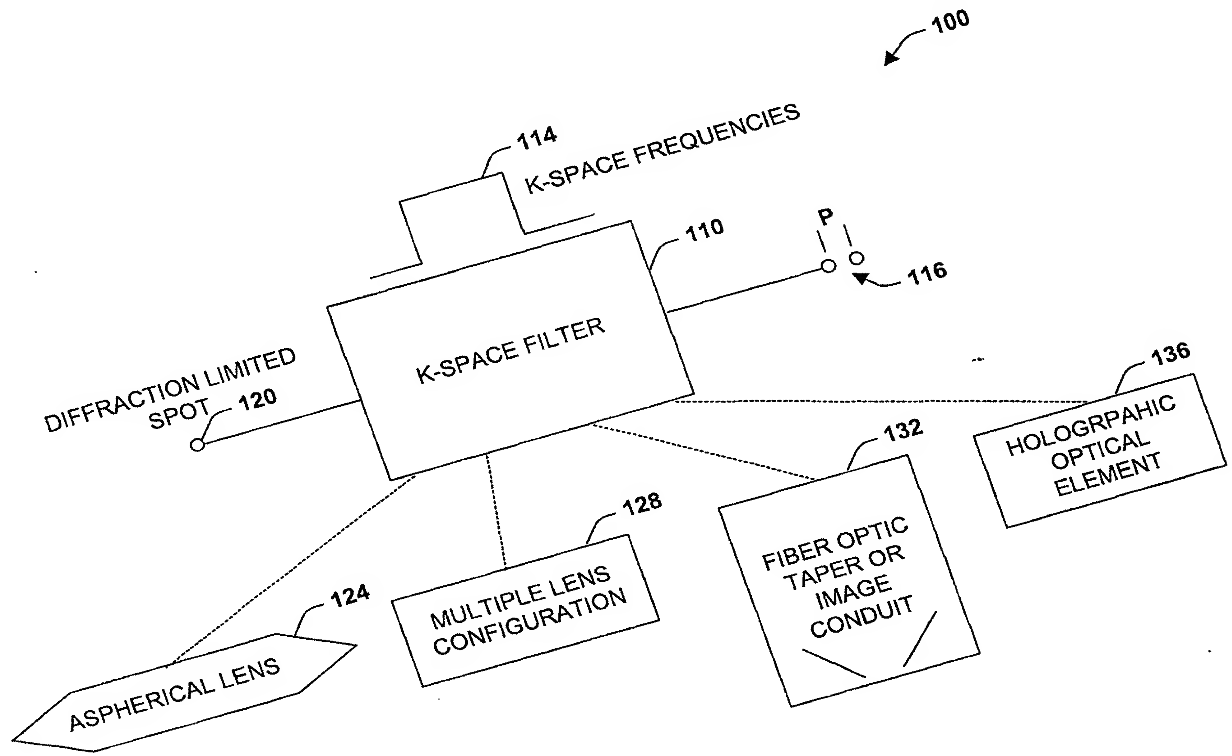
100
114
K-SPACE FREQUENCIES
110
P
116
K-SPACE FILTER
DIFFRACTION LIMITED SPOT
120
136
HOLOGRPAHIC OPTICAL ELEMENT
132
FIBER OPTIC TAPER OR IMAGE CONDUIT
128
MULTIPLE LENS CONFIGURATION
124
ASPHERICAL LENS

Fig. 2

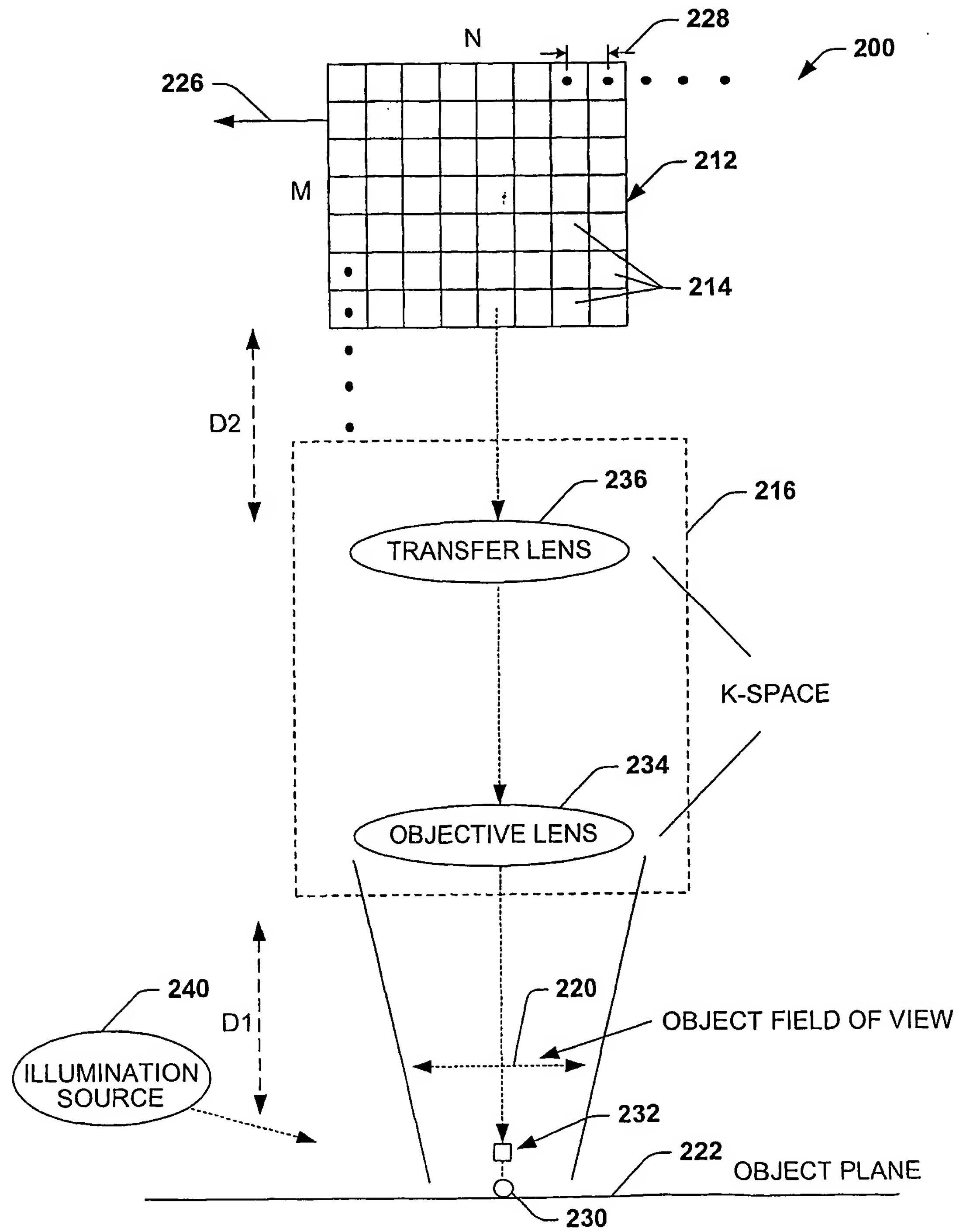
N
228
200
226
212
M
214
D2
236
216
TRANSFER LENS
K-SPACE
234
OBJECTIVE LENS
240
220
D1
OBJECT FIELD OF VIEW
ILLUMINATION SOURCE
232
222
OBJECT PLANE
230

Fig. 3

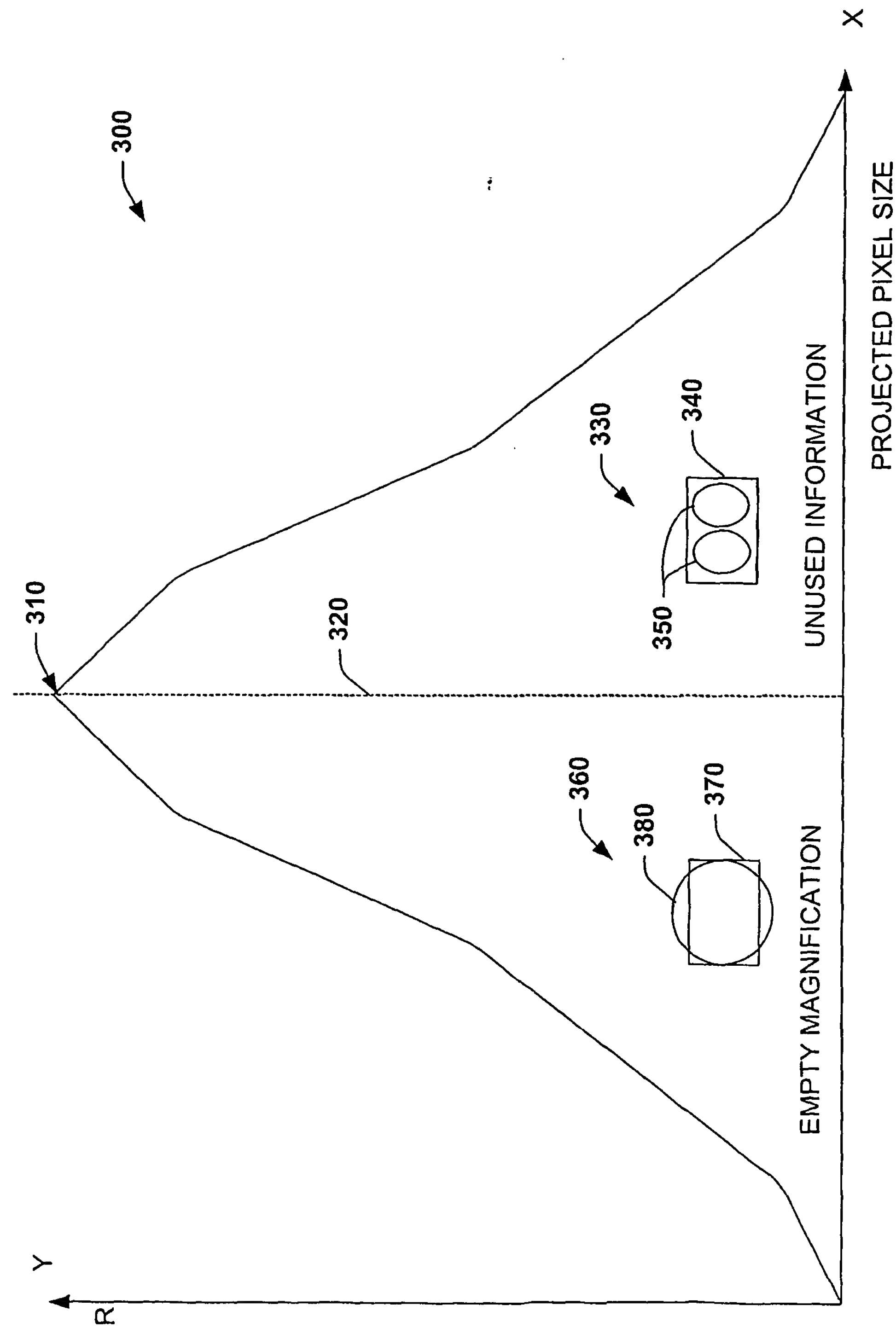
300
310
320
330
340
350
360
370
380
UNUSED INFORMATION
EMPTY MAGNIFICATION
PROJECTED PIXEL SIZE
X
Y
R

Fig. 4

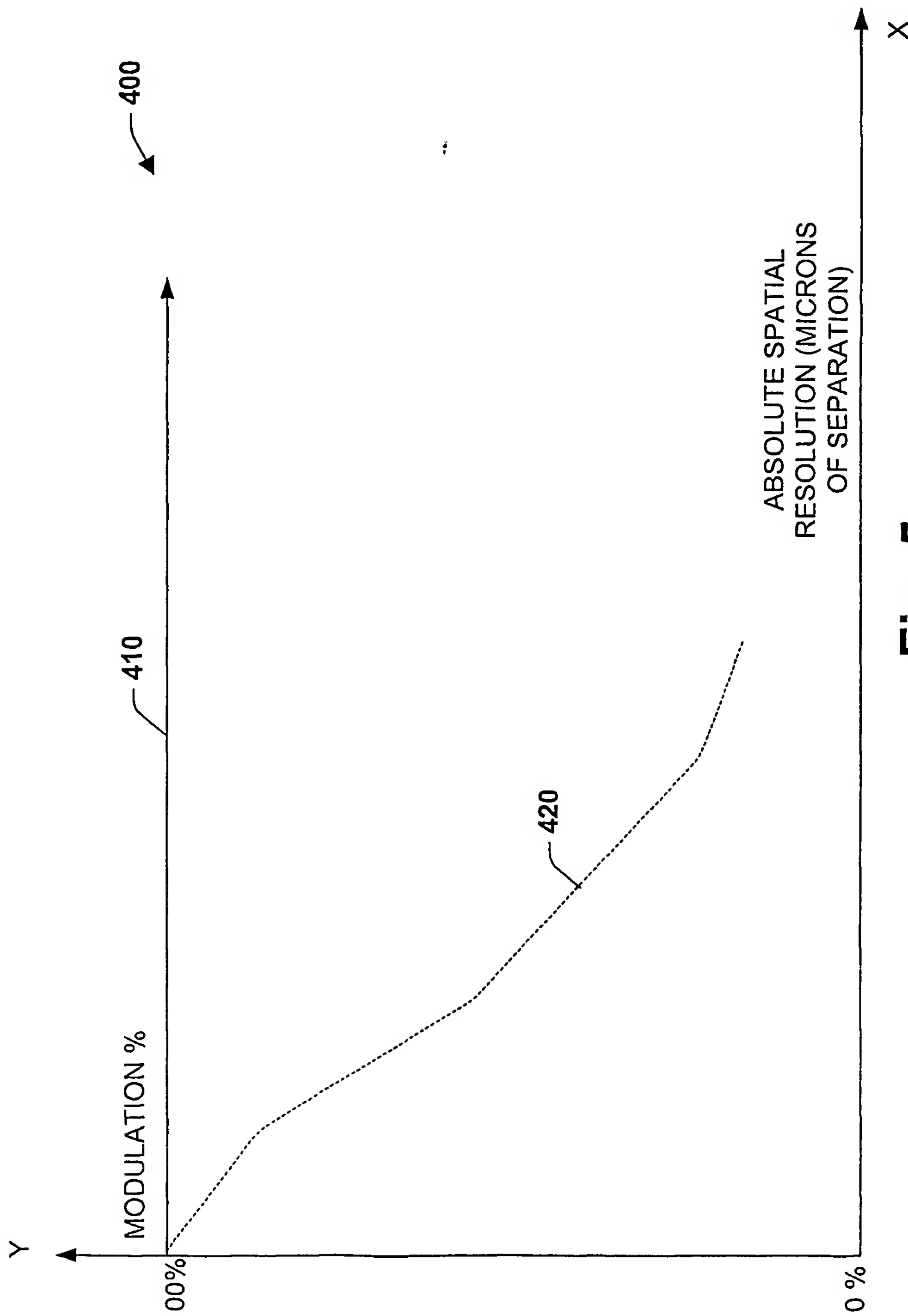
400
410
420
MODULATION %
Y
100%
0 %
ABSOLUTE SPATIAL RESOLUTION (MICRONS OF SEPARATION)
X

Fig. 5

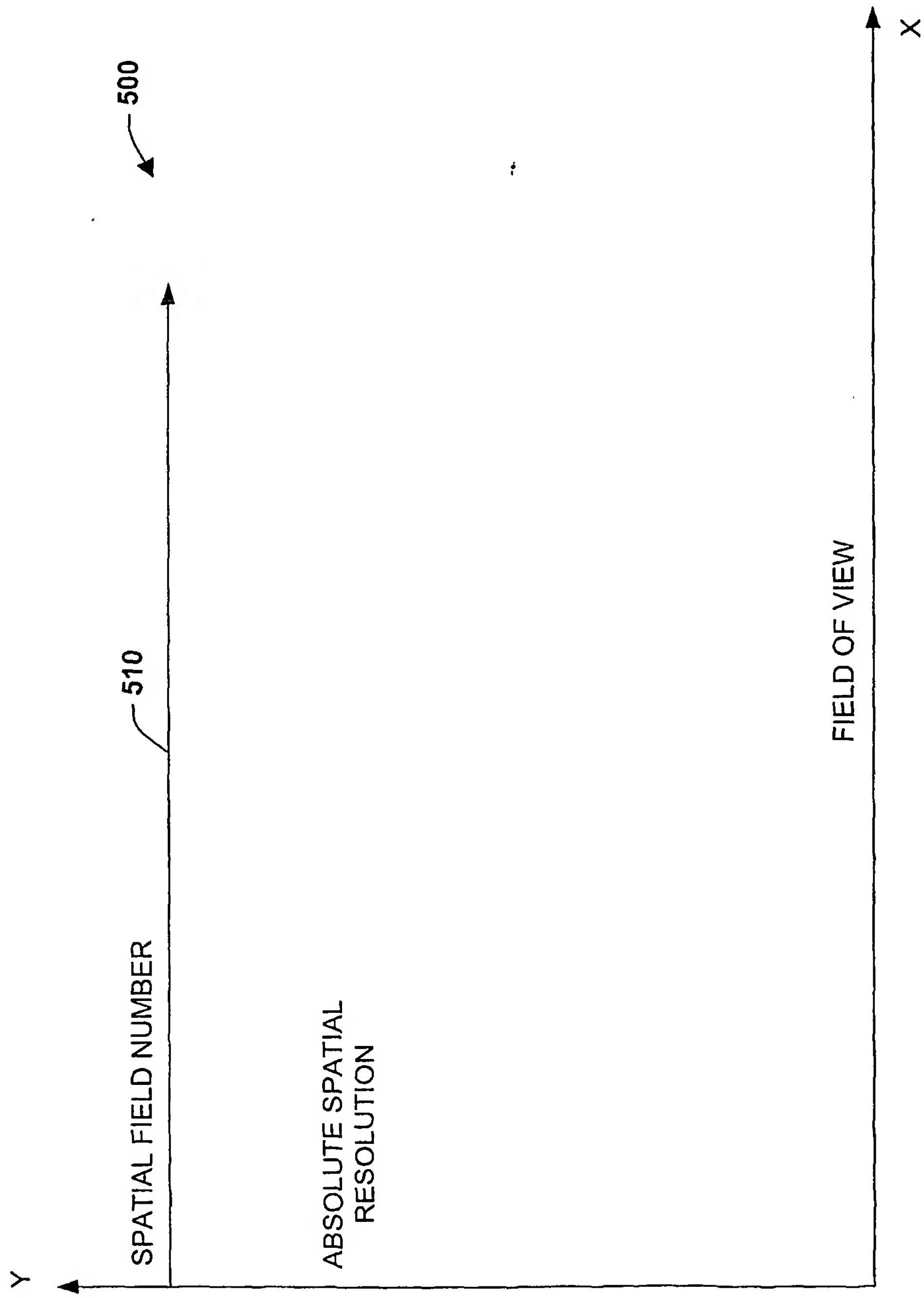
500
510
SPATIAL FIELD NUMBER
ABSOLUTE SPATIAL RESOLUTION
FIELD OF VIEW
X
Y

Fig. 6

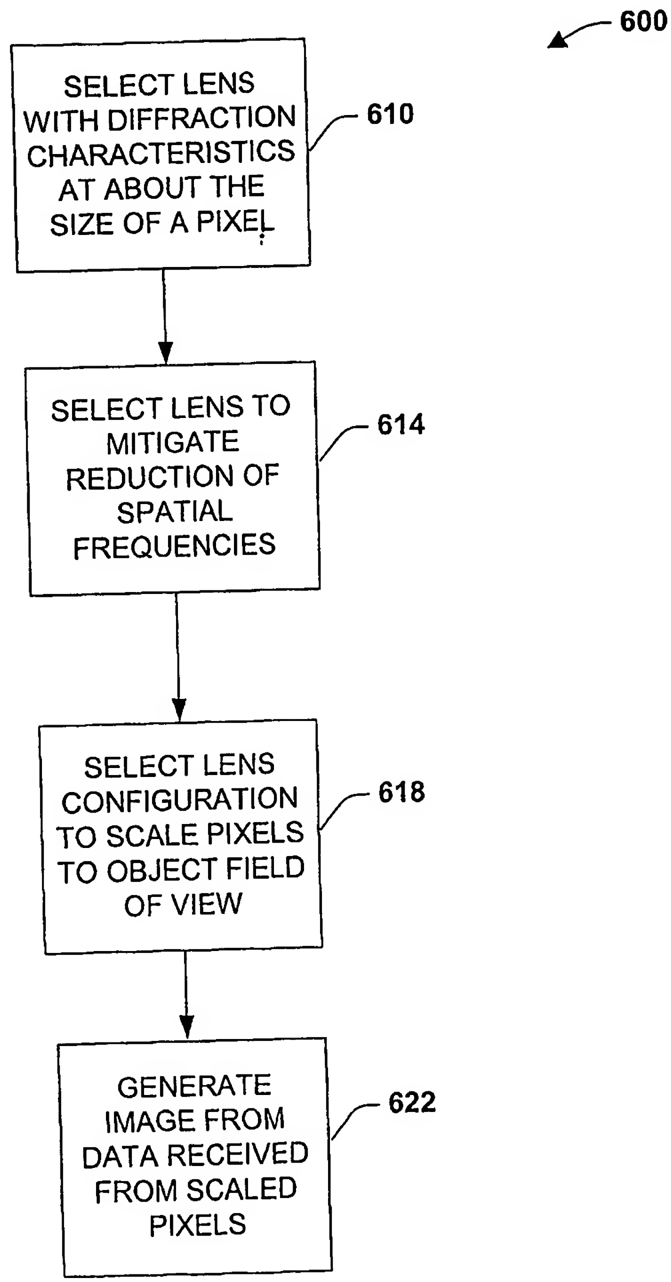
600
SELECT LENS WITH DIFFRACTION CHARACTERISTICS AT ABOUT THE SIZE OF A PIXEL
610
SELECT LENS TO MITIGATE REDUCTION OF SPATIAL FREQUENCIES
614
SELECT LENS CONFIGURATION TO SCALE PIXELS TO OBJECT FIELD OF VIEW
618
GENERATE IMAGE FROM DATA RECEIVED FROM SCALED PIXELS
622

Fig. 7

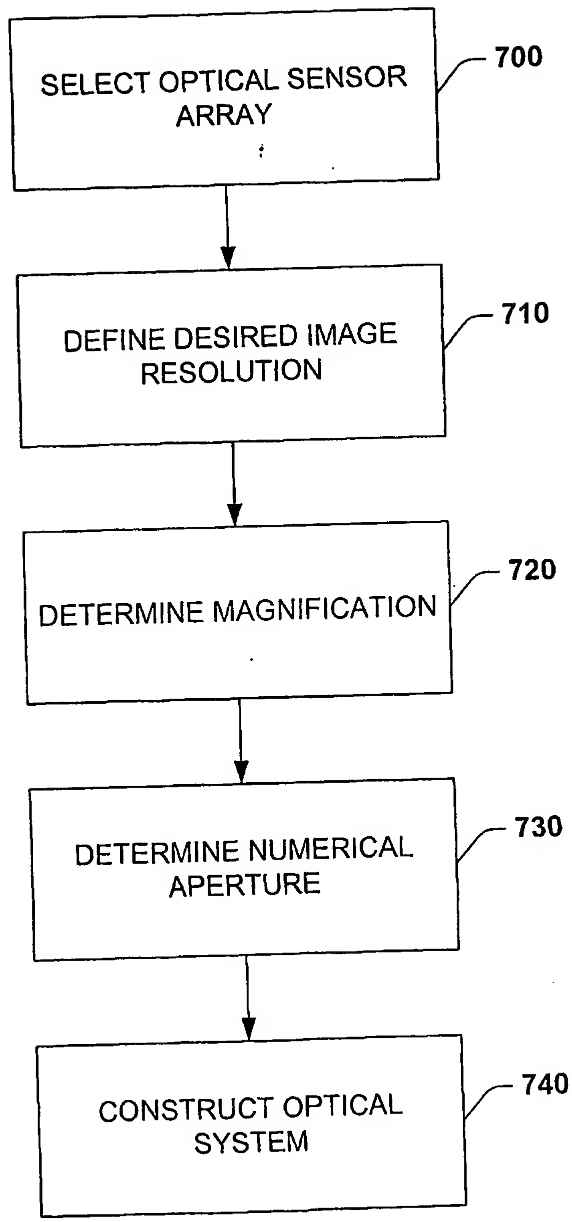
SELECT OPTICAL SENSOR ARRAY
700
DEFINE DESIRED IMAGE RESOLUTION
710
DETERMINE MAGNIFICATION
720
DETERMINE NUMERICAL APERTURE
730
CONSTRUCT OPTICAL SYSTEM
740

Fig. 8

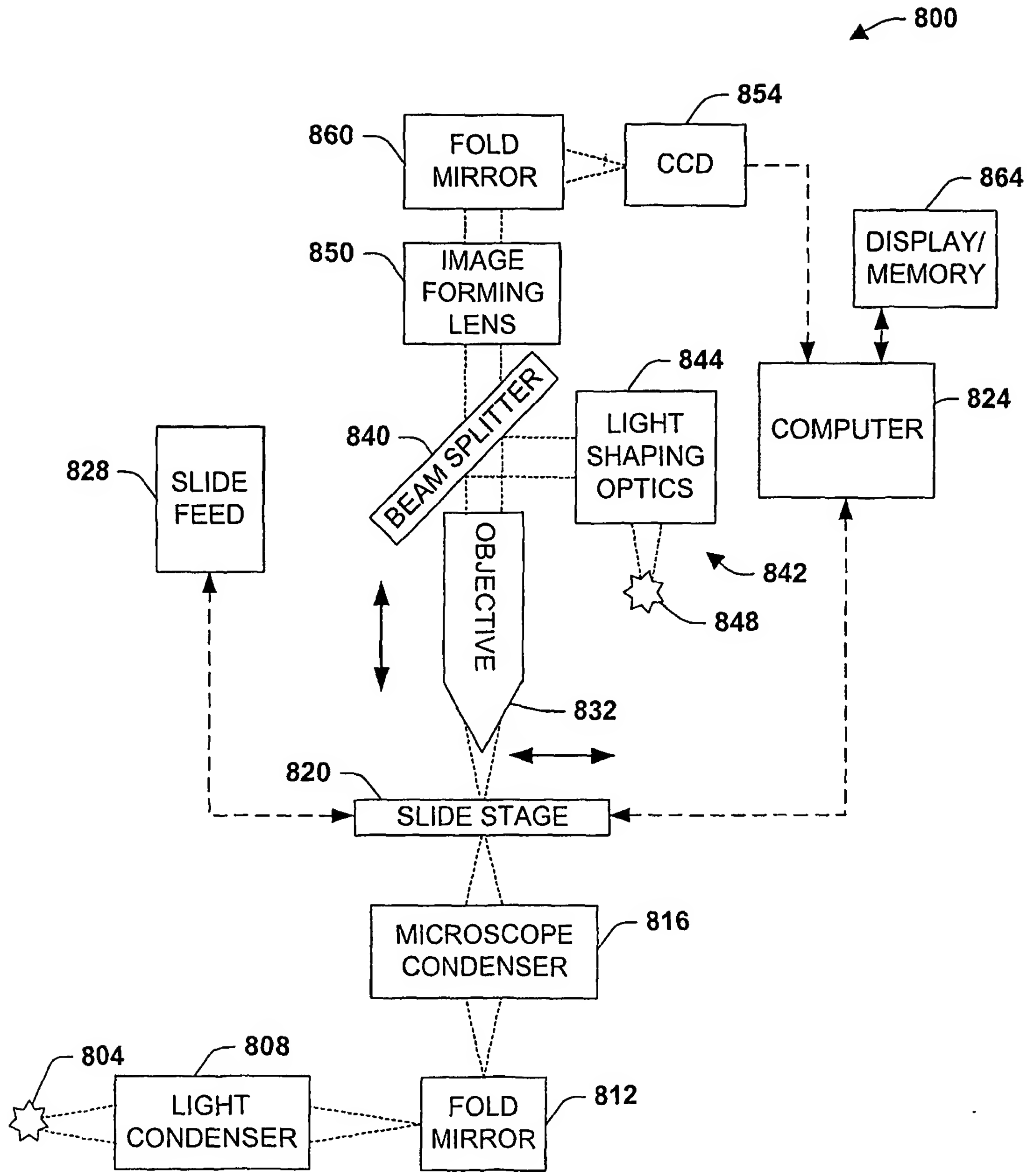
800
854
860
FOLD MIRROR
CCD
864
DISPLAY/ MEMORY
850
IMAGE FORMING LENS
844
824
BEAM SPLITTER
LIGHT SHAPING OPTICS
COMPUTER
840
828
SLIDE FEED
842
OBJECTIVE
848
832
820
SLIDE STAGE
MICROSCOPE CONDENSER
816
804
808
LIGHT CONDENSER
FOLD MIRROR
812

Fig. 9

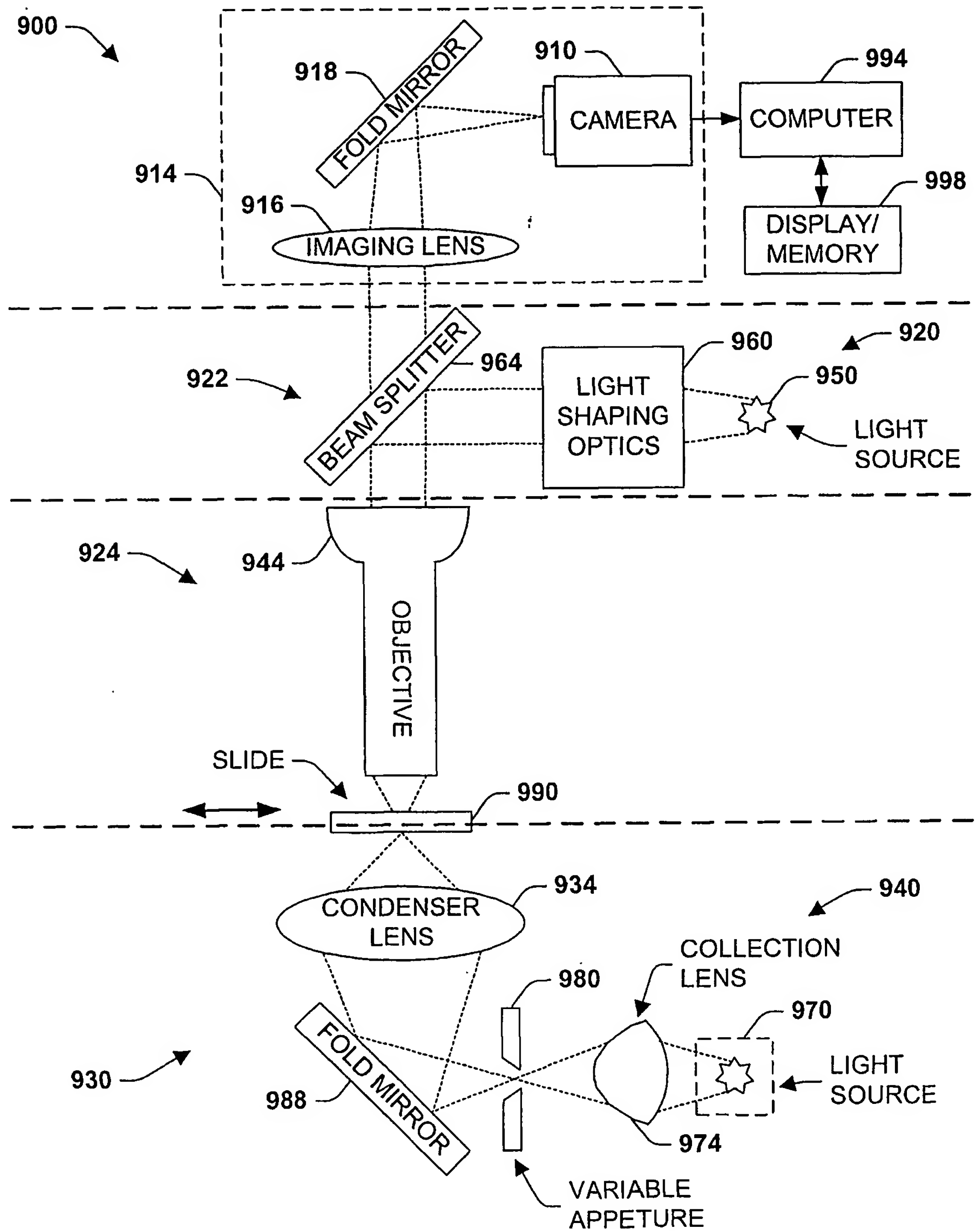
900
918
FOLD MIRROR
910
CAMERA
994
COMPUTER
914
916
IMAGING LENS
998
DISPLAY/
MEMORY
922
BEAM SPLITTER
964
LIGHT
SHAPING
OPTICS
960
920
950
LIGHT
SOURCE
924
944
OBJECTIVE
SLIDE
990
934
CONDENSER
LENS
940
COLLECTION
LENS
980
970
930
988
FOLD MIRROR
LIGHT
SOURCE
974
VARIABLE
APPETURE

Fig. 10

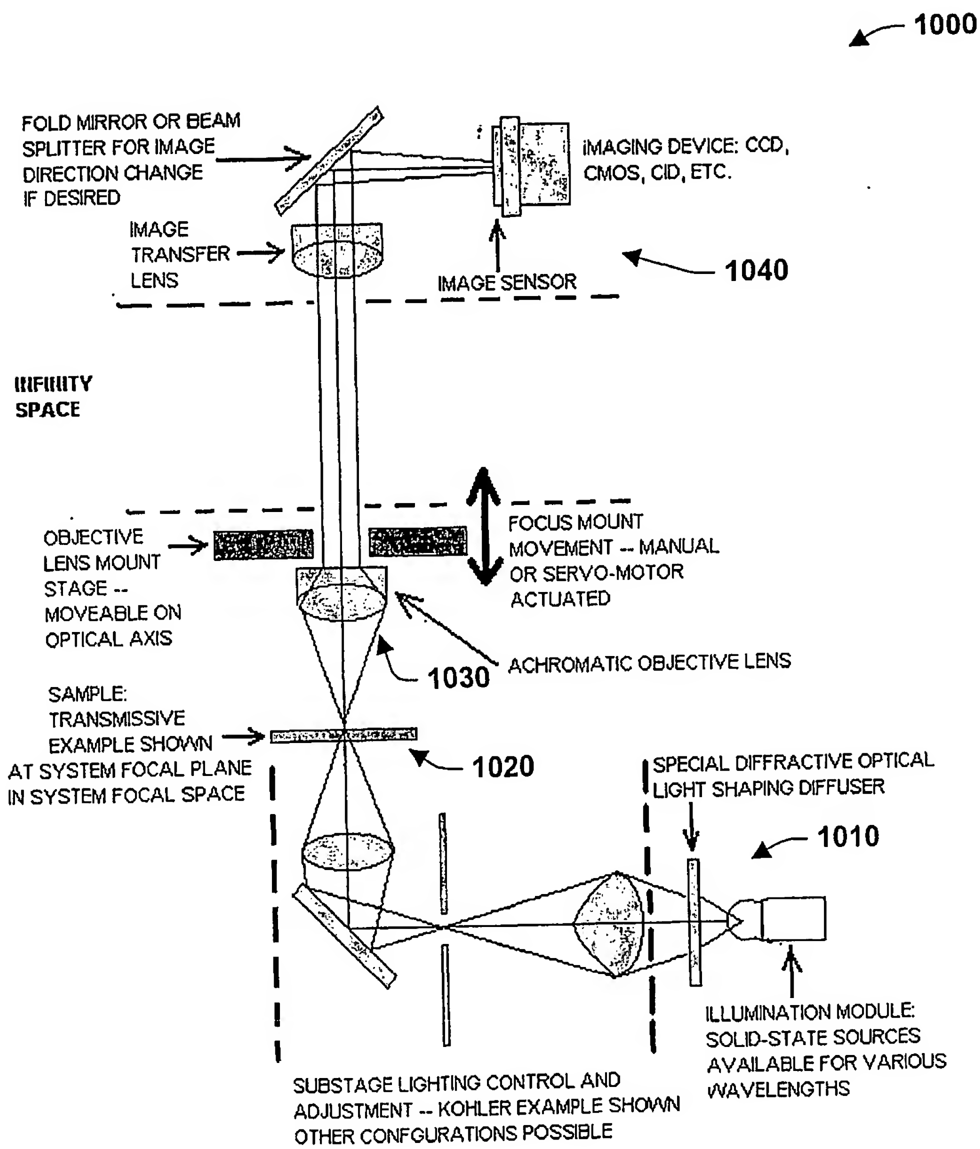
1000
FOLD MIRROR OR BEAM SPLITTER FOR IMAGE DIRECTION CHANGE IF DESIRED
IMAGING DEVICE: CCD, CMOS, CID, ETC.
IMAGE TRANSFER LENS
IMAGE SENSOR
1040
INFINITY SPACE
OBJECTIVE LENS MOUNT STAGE -- MOVEABLE ON OPTICAL AXIS
FOCUS MOUNT MOVEMENT -- MANUAL OR SERVO-MOTOR ACTUATED
1030
ACHROMATIC OBJECTIVE LENS
SAMPLE: TRANSMISSIVE EXAMPLE SHOWN AT SYSTEM FOCAL PLANE IN SYSTEM FOCAL SPACE
1020
SPECIAL DIFFRACTIVE OPTICAL LIGHT SHAPING DIFFUSER
1010
ILLUMINATION MODULE: SOLID-STATE SOURCES AVAILABLE FOR VARIOUS WAVELENGTHS
SUBSTAGE LIGHTING CONTROL AND ADJUSTMENT -- KOHLER EXAMPLE SHOWN OTHER CONFGURATIONS POSSIBLE

Fig. 11

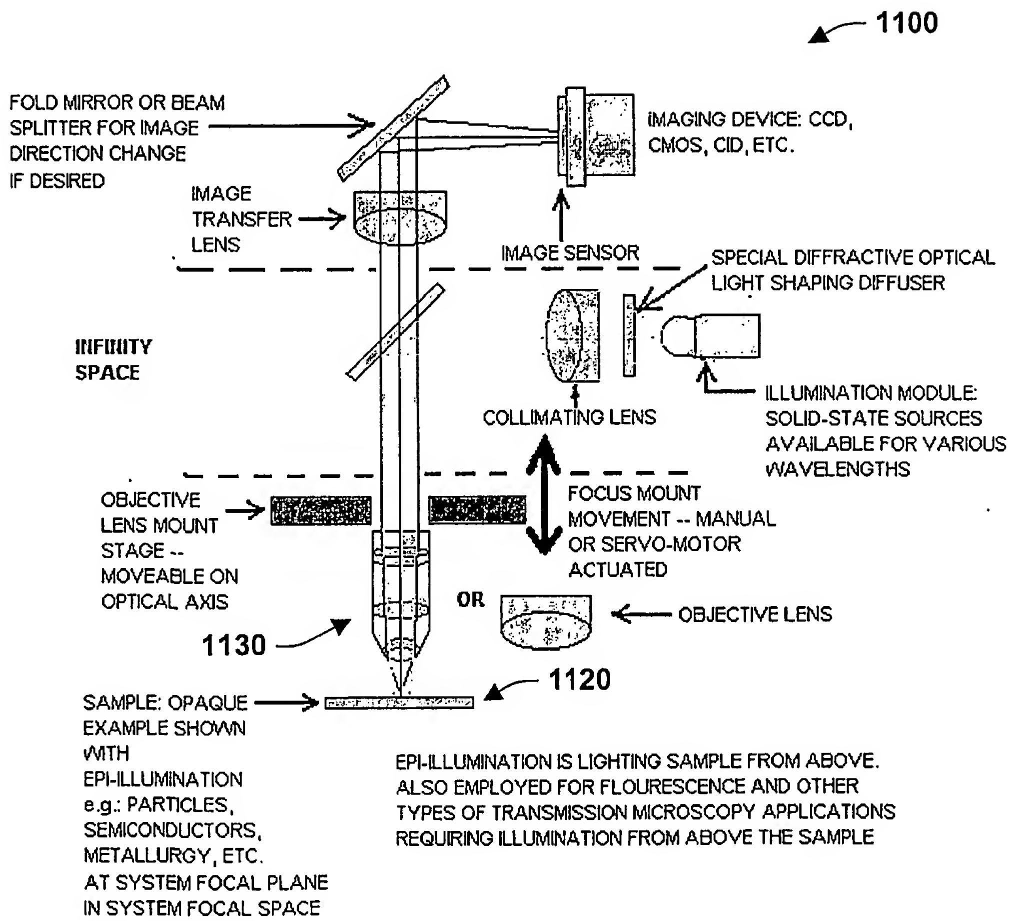
1100
FOLD MIRROR OR BEAM SPLITTER FOR IMAGE DIRECTION CHANGE IF DESIRED
IMAGING DEVICE: CCD, CMOS, CID, ETC.
IMAGE TRANSFER LENS
IMAGE SENSOR
SPECIAL DIFFRACTIVE OPTICAL LIGHT SHAPING DIFFUSER
INFINITY SPACE
COLLIMATING LENS
ILLUMINATION MODULE: SOLID-STATE SOURCES AVAILABLE FOR VARIOUS WAVELENGTHS
OBJECTIVE LENS MOUNT STAGE -- MOVEABLE ON OPTICAL AXIS
FOCUS MOUNT MOVEMENT -- MANUAL OR SERVO-MOTOR ACTUATED
OR
OBJECTIVE LENS
1130
1120
SAMPLE: OPAQUE EXAMPLE SHOWN WITH EPI-ILLUMINATION e.g.: PARTICLES, SEMICONDUCTORS, METALLURGY, ETC. AT SYSTEM FOCAL PLANE IN SYSTEM FOCAL SPACE
EPI-ILLUMINATION IS LIGHTING SAMPLE FROM ABOVE. ALSO EMPLOYED FOR FLOURESCENCE AND OTHER TYPES OF TRANSMISSION MICROSCOPY APPLICATIONS REQUIRING ILLUMINATION FROM ABOVE THE SAMPLE

Fig. 12

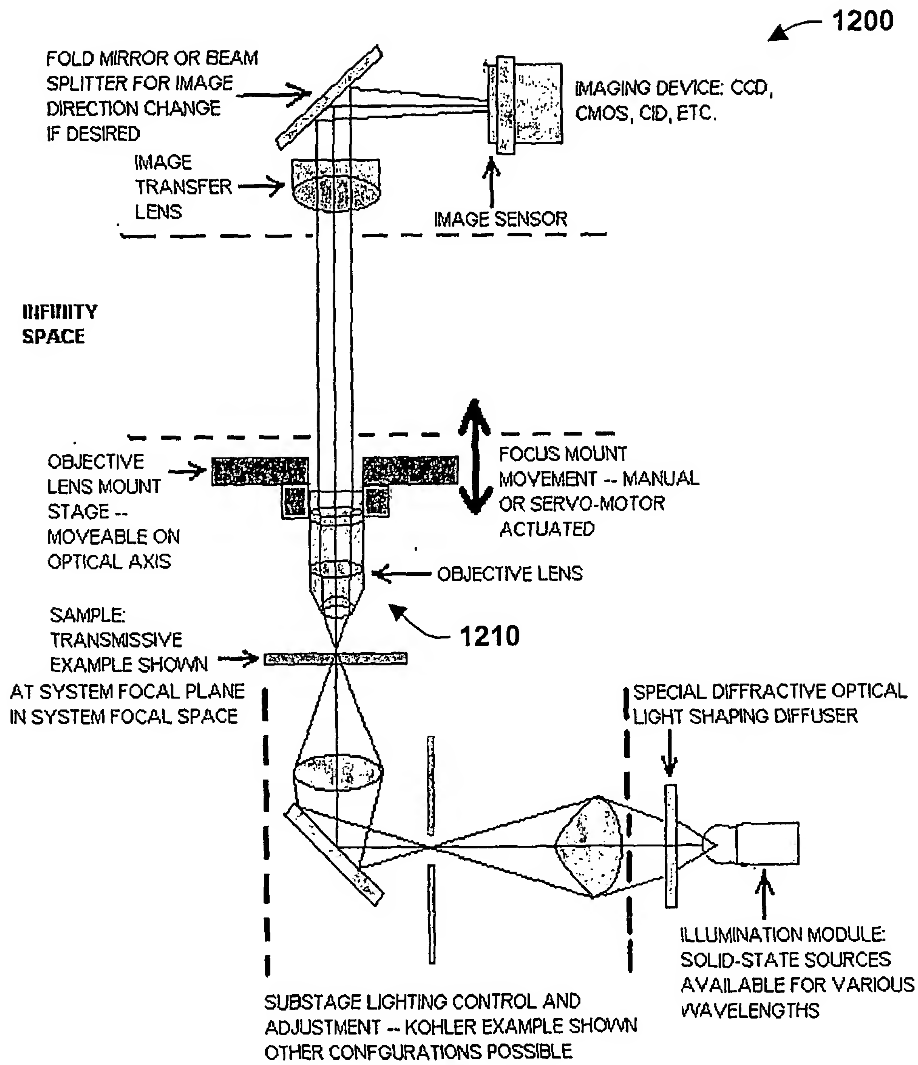
1200
FOLD MIRROR OR BEAM SPLITTER FOR IMAGE DIRECTION CHANGE IF DESIRED
IMAGING DEVICE: CCD, CMOS, CID, ETC.
IMAGE TRANSFER LENS
IMAGE SENSOR
INFINITY SPACE
OBJECTIVE LENS MOUNT STAGE -- MOVEABLE ON OPTICAL AXIS
FOCUS MOUNT MOVEMENT -- MANUAL OR SERVO-MOTOR ACTUATED
OBJECTIVE LENS
SAMPLE: TRANSMISSIVE EXAMPLE SHOWN
1210
AT SYSTEM FOCAL PLANE IN SYSTEM FOCAL SPACE
SPECIAL DIFFRACTIVE OPTICAL LIGHT SHAPING DIFFUSER
ILLUMINATION MODULE: SOLID-STATE SOURCES AVAILABLE FOR VARIOUS WAVELENGTHS
SUBSTAGE LIGHTING CONTROL AND ADJUSTMENT -- KOHLER EXAMPLE SHOWN OTHER CONFGURATIONS POSSIBLE

Fig. 13

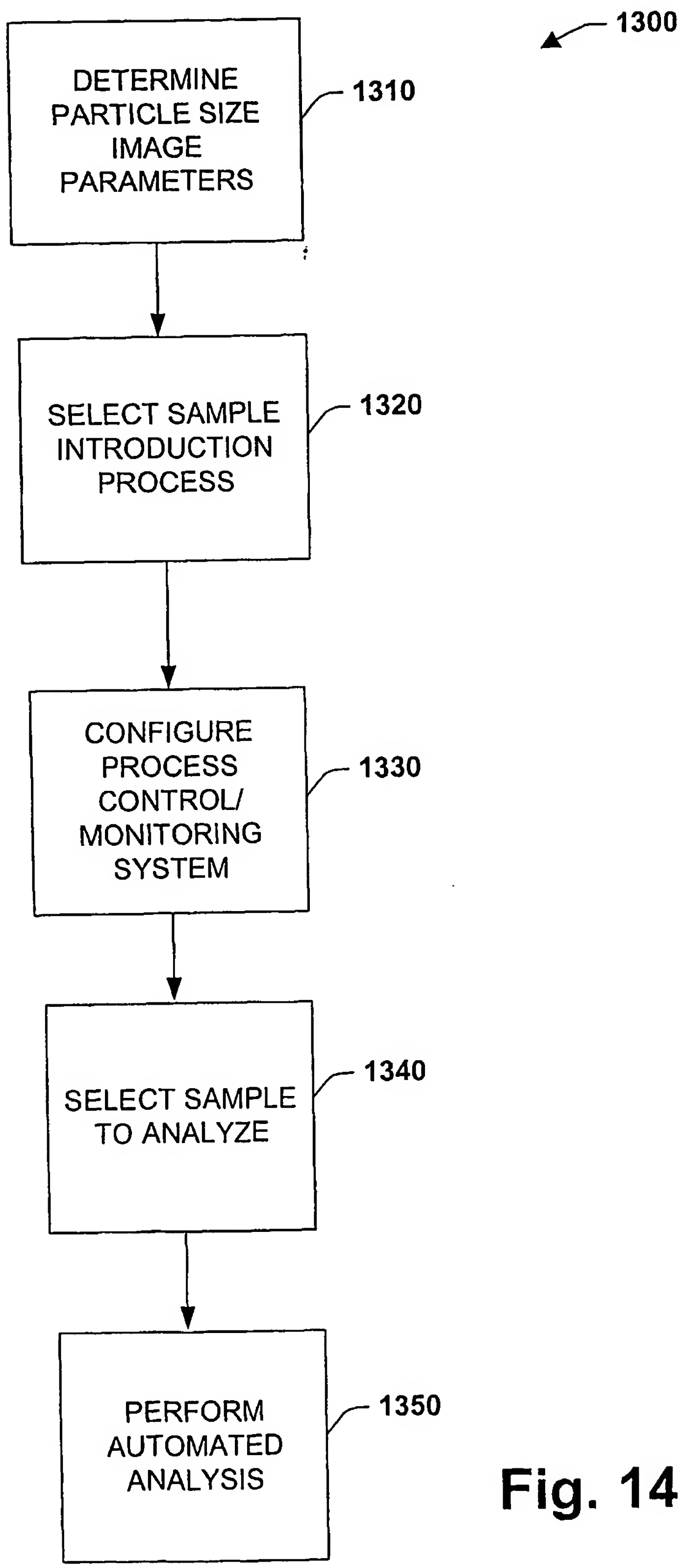
1300
DETERMINE PARTICLE SIZE IMAGE PARAMETERS
1310
SELECT SAMPLE INTRODUCTION PROCESS
1320
CONFIGURE PROCESS CONTROL/ MONITORING SYSTEM
1330
SELECT SAMPLE TO ANALYZE
1340
PERFORM AUTOMATED ANALYSIS
1350

Fig. 14

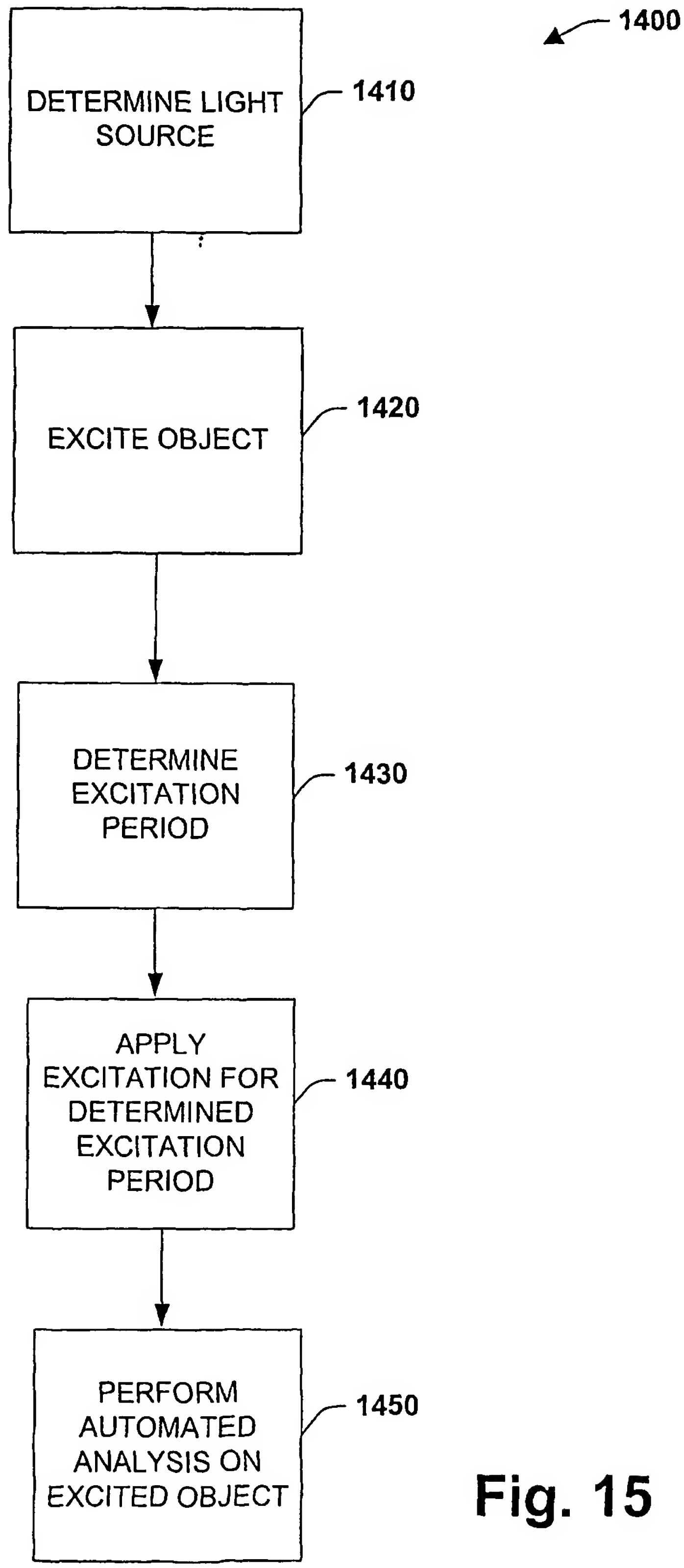
1400
DETERMINE LIGHT SOURCE
1410
EXCITE OBJECT
1420
DETERMINE EXCITATION PERIOD
1430
APPLY EXCITATION FOR DETERMINED EXCITATION PERIOD
1440
PERFORM AUTOMATED ANALYSIS ON EXCITED OBJECT
1450

Fig. 15

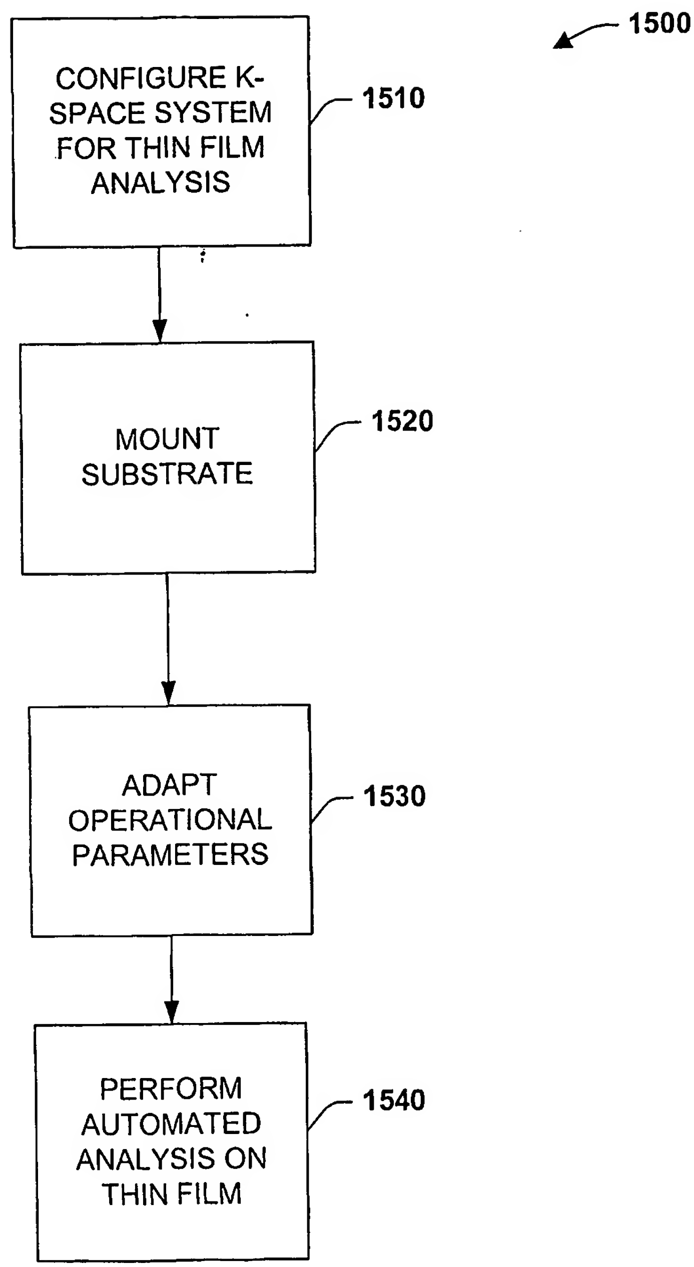
1500
CONFIGURE K-SPACE SYSTEM FOR THIN FILM ANALYSIS
1510
MOUNT SUBSTRATE
1520
ADAPT OPERATIONAL PARAMETERS
1530
PERFORM AUTOMATED ANALYSIS ON THIN FILM
1540

Fig. 16

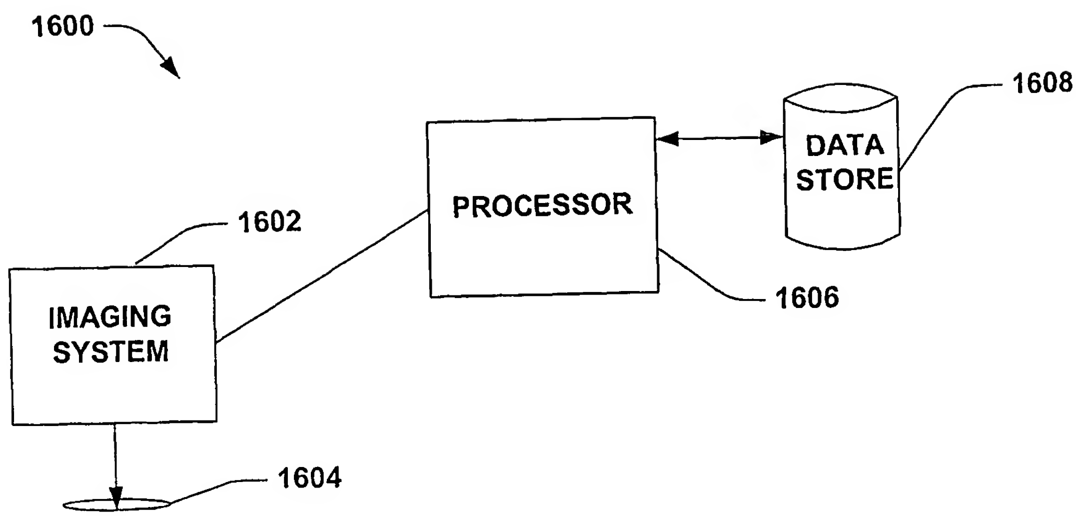
1600
1608
DATA
STORE
PROCESSOR
1602
1606
IMAGING
SYSTEM
1604

Fig. 17

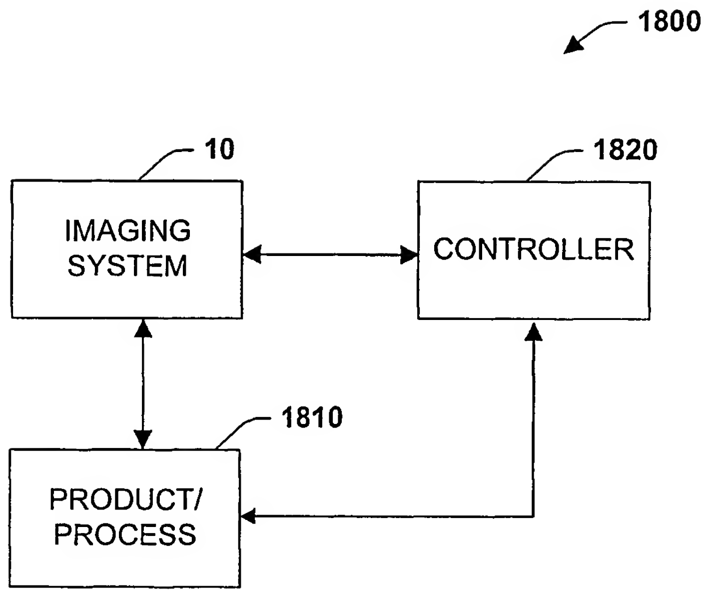
1800
10
IMAGING SYSTEM
1820
CONTROLLER
1810
PRODUCT/ PROCESS

Fig. 18

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US02/21392

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : H01L 27/00; G02B 27/40; G06K 9/76
US CL : 250/208.1, 201.3; 359/15; 382/210
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 250/208.1, 201.3, 201.9; 359/15, 9, 26; 382/210, 134

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Please See Continuation Sheet

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,973,844 A (BURGER) 26 October 1999 (26.10.1999), see the entire document.	1-12
X	US 5,198,653 A (SHEN et al.) 30 March 1993 (30.03.1993), see the entire document.	1-5
A	US 6,248,988 B1 (KRANTZ) 19 June 2001 (19.06.2001), see the entire document.	1-12

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 09 September 2002 (09.09.2002)	Date of mailing of the international search report 12 NOV 2002
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703)305-3230	Authorized officer SEUNG C. SOHN Telephone No. (703) 308-4093

Continuation of B. FIELDS SEARCHED Item 3:
EAST
SEARCH TERMS:

(k-space or reciprocal-space) near filter
"object field of view"
"field of view"
((k or reciprocal) near space) near filter
"modulation transfer function"
"modulation transfer function" and ((((recept$4 or pixel$2 or sens$4) near (scal$4 or map$4 or siz$4 or project$4 or match$4 or reduc$4)) and 250/$.ccls.) and microscop$4)
unit-map$4 or (unit near map$4)
(((microscop$4.ti. and (250/$.ccls or 359/$.ccls.)) and ccd) and led) and (wavelength-specific or brodband or continuous or strobed or kohler or abbe or phase-contrast or darkfield or brightfield or epi)
pitch$2 with pixel$2
"working distance"